

**The Topography (And Ephemeris) Of Phobos From MOLA Ranging.** W. B. Banerdt<sup>1</sup> and G. A. Neumann<sup>2</sup>,  
<sup>1</sup>Jet Propulsion Laboratory, Caltech, MS 183-501, 4800 Oak Grove Dr., Pasadena, CA 91109, [bruce.banerdt@jpl.nasa.gov](mailto:bruce.banerdt@jpl.nasa.gov), <sup>2</sup>Goddard Space Flight Center, Laboratory for Terrestrial Physics, Code 920, Greenbelt, MD 20771, [neumann@tharsis.gsfc.nasa.gov](mailto:neumann@tharsis.gsfc.nasa.gov).

The MGS spacecraft experienced four close encounters with Phobos in the late summer of 1998. The last (and closest) of these, on September 12, 1998, had an encounter distance of 265 km, well within the maximum MOLA range of 780 km. The apparent motion of Phobos at encounter was 0.7°/sec (well in excess of the maximum MGS roll rate of 0.3°/sec), which would have resulted in about 6 seconds on target for a fixed spacecraft orientation, or about 10 seconds using a spacecraft roll to partially compensate for the motion. A scheme was devised to maximize the ranging time on Phobos by overtaking the trailing limb with the MGS slew while at a distance (roughly 530 km) such that the apparent motion of Phobos was still less than 0.3°/sec. As the track crossed Phobos and the distance decreased, the increase in the apparent motion slowed and eventually reversed the track before the entire disk was traversed. The track then re-crossed the trailing limb at a range of about 350 km. This operation resulted in the first successful active spacecraft ranging to a small body, with nearly 70 seconds of time on target and 627 valid ranging measurements along two nearly coincident, but slightly offset tracks (see Figure 1). These tracks cross the Mars-facing hemisphere from SE to NW, covering a length of about 120° of arc. At these ranges the laser footprint varied in size from 130 to 200 m and the footprint spacing ranged from less than 10 m near the reversal point to a few hundred meters near the limb. Successful returns were obtained at emission angles up to 80°.

However, problems arose when comparing the MOLA data to existing image maps [1,2] and shape models [3,4]. First, topographic features in the ranging data do not correlate with visible features in maps. The nominal groundtrack crossed several craters and grooves, none of which could be identified in the MOLA data. Conversely, substantial topographic signatures in the data had no counterpart in the maps. In addition the overall shape defined by the MOLA data is in poor agreement with the established shape of Phobos, with deviations of several kilometers. Both problems are clearly associated with errors in the groundtrack location. This is a common problem with MOLA data analysis, as uncertainties in the location data (ephemeris and geodetic control of the target, ephemeris and pointing accuracy of the spacecraft) are generally much larger than the size of the footprint. In this case, the error is dominated by the Phobos ephemeris, with 1- $\sigma$  uncertainties of about 5 km

along track, 3 km out of plane, and 1 km radially (after a preliminary refinement using MOC data from the first three encounters [5]) and the MGS ephemeris, with 1- $\sigma$  uncertainties of a kilometer along track and a few hundred meters cross-track [6]. The MGS uncertainties are larger than normal because tracking data was not acquired for this orbit due to a spacecraft anomaly.

The standard method of correcting track location is by correlating topographic signatures in the MOLA data with well-defined features in maps. Feature correlation is difficult on Phobos due to the uneven imaging coverage and the generally small size of the features themselves. However on the western end of the track we have been able to identify a correlation with several features (three craters, the rim of a fourth crater, and an irregular pit) within a 5-km interval. This correlation indicates that a shift in the groundtrack of 18° to the east and 6.5° to the north is required in that region. Because of the small radius and irregular geometry of Phobos and the large and variable emission angles of the ranging, this correction is not constant along the track and cannot be made for its entire length by simply "sliding" the computed groundtrack (as is commonly done locally for track corrections). Instead, it is necessary to adjust the relative position of MGS and Phobos appropriately and re-compute the reflection points relative to the Phobos center.

We have made the correction by adjusting the relative position of MGS and Phobos assuming that the errors are due entirely to along-track position errors (which can be represented in terms of timing errors) of Phobos and MGS (the two orbit tracks are nearly orthogonal). The required ground track shift can be achieved with a 1.75 second (3.8 km) adjustment to Phobos and a -0.45 second (1.1 km) adjustment to MGS. Note that these shifts are considerably less than the combined uncertainties. We then recomputed the reflection point positions, resulting in a corrected groundtrack and topographic profile as shown in Figures 1 and 2.

The excellent agreement between the corrected topographic profiles and the previously determined shape of Phobos shown in Figure 2 provides a second independent measure of the quality of the position adjustment. These profiles now correlate to within 200 meters, whereas previously they were several kilometers out of agreement. Thus we are now confident that the MOLA radius data can now be used for quantitative studies of the shape of Phobos and the morphology of its surface features [e.g., 6].

Our analysis provides a tight constraint on the position of Phobos at the time of the MOLA ranging experiment. Table 1 lists the correction to the ephemeris that is necessary to correct the MOLA data. This correction (the corrected position minus the nominal position) has been computed for the time at which the MOLA track reversed, and is expressed for Phobos in reference frame J2000. There is a roughly 4-km offset in the actual position relative to the expected position, with an uncertainty determined by that of MGS (roughly 1 km).

**References:** [1] D.P. Simonelli et al. (1993) *Icarus*, 103, 49. [2] P.J. Stooke, pers. comm. [3] P.C. Thomas (1993) *Icarus*, 105, 326. [4] R.M. Batson et al. (1992) *Mars*, 1249. [5] S. Synnott, pers. comm. [6] J. Garvin and W.B. Banerdt (1999) this volume.

Table 1. Phobos Ephemeris Correction

Ephemeris Time	-41087665.176
$\Delta X$	0.378 km
$\Delta Y$	-3.063 km
$\Delta Z$	-2.404 km
Magnitude	3.912 km

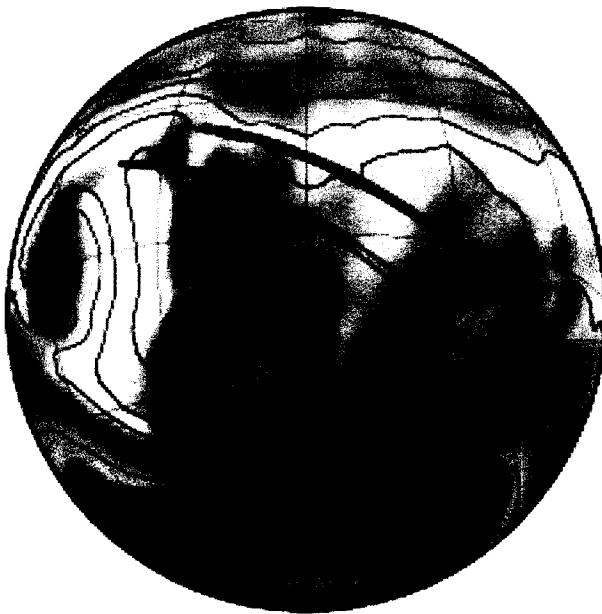


Figure 1. MOLA groundtracks superimposed on the Phobos shape model of Thomas [3] (spherical projection is centered at 0°W15°S). Blue points are the nominally predicted footprint locations, black and green points are the corrected locations for the inbound and outbound tracks, respectively.

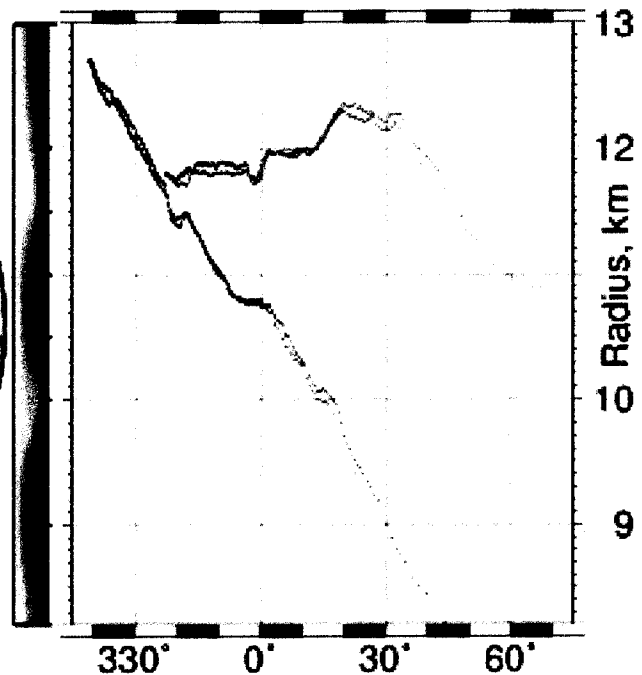


Figure 2. Phobos radii. Blue, black, and green points are as defined in Figure 1. Red lines are profiles of the shape model along the corrected tracks. The MOLA radii and photogrammetrically determined radii now agree at the few hundred meter level.